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FILM DOSIMETER PERFORMANCE CRITERIA AND
AN ASSESSMENT OF CURRENT PERFORMANCE LEVELS^(a)

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ABSTRACT

A two-year study of personnel dosimeter performance capabilities and current levels of performance was recently completed. Thirty-five film processors participated in the study. The criteria to define performance levels based on current technical capabilities were formulated as a two-part performance specification. Specifications for both variance and bias were established. Equations to relate the performance level with the dose range of interest for ten types of radiations or combinations of radiations are presented. The range of variance and bias observed for commercial, AEC contractors and military processors is presented and compared.

A nationally established calibration laboratory that would conduct exposures of calibration film sets for any, and hopefully all, film processors would provide a mechanism to virtually eliminate bias from all processing facilities at a nominal cost. Action to adopt the recommended performance criteria and to assist film processors by providing a top-quality dosimeter film calibration service on at least a voluntary basis should be established soon.

Since 1955, at least seven studies have considered the evaluation of film dosimeter processor performance or the establishment of film dosimeter performance criteria. The National Sanitation Foundation (NSF) has provided a basis for the film dosimeter processors to meet together and to establish self-imposed performance standards. The National Sanitation Foundation has issued seals of approval to qualifying processors meeting their performance criteria.

The study described here was performed by Battelle-Northwest and had as its overall objective the development of a system to provide users of film processing services and regulatory agencies with a means of assuring that adequate film dosimetry is being provided. The specific objectives of the study were:

- The development of practical and meaningful film dosimeter performance criteria.
- The determination of the need for establishing a Film Dosimeter Evaluation Program to identify processors who are providing adequate technical service.
- The development of a system of administrative and technical procedures for implementing the Evaluation Program if the need is indicated.
- The identification of facilities, equipment, staff and costs for the establishment and operation of a Film Dosimetry Calibration Laboratory in which to conduct the Evaluation Program if the Program is deemed necessary or desirable.

We will review here only the first two of these objectives. There are a number of approaches that may be used to develop film dosimeter performance criteria.

First, the study of fundamental film performance data collected by conducting controlled physics type experiments could be used as a basis for establishing performance criteria.

A second approach considered was the selection of a single film dosimeter processor judged to operate in a fully satisfactory manner and having fully adequate equipment and then measure his actual performance.

A third method was to conduct an extensive performance evaluation study of all the industry and to evaluate the observed average performance. The average performance would then be used to derive the Performance Criteria.

A fourth method of criteria development is to select a group of processors comprised of a reasonable percentage of the processors and to use their observed performance in a test irradiation program as a basis for criteria establishment. In this group it is necessary to select only processors judged to have adequate equipment, and to use adequate methods of operation. These judgments of adequacy are subjective and based on the past experience of those making the selection. This method of performance criteria development was selected for use in this study. It provides performance criteria that can be reasonably attained with a reasonable complement of equipment, personnel and operating methods. Also, it provides the best measure of what is technologically feasible and practical at the current time with processing equipment and methods in general use. Although many variations pertaining to the size of the processor group selected can be made, the performance criteria developed does not change substantially with the addition or deletion of a few to the selected group of processors.

In this study expert judgment was utilized to identify technically sound processors whose observed performance was subsequently analyzed as a basis for derivation of the performance criteria presented. The judgment was used to identify, prior to the irradiation tests, five processors providing service in each radiation category whose methods and equipment were judged to have good capability for performing film dosimeter processing and evaluation. Processors from both private industry and from the AEC complex were included in this group of five. The data from these five processors were analyzed and performance criteria were calculated from this data analysis to assure a high probability that two of these five processors always would meet the performance criteria so long as their methods are not changed significantly. The other three

processors would have only a slight chance of failing to meet the criteria on any single test. The data from all processors were used to determine the effects of the criteria on the industry.

The number of dosimeters required for the test irradiation program was determined by examining Hanford personnel film badge dosimeter data for the past 14 years. A test irradiation program was devised to provide equally precise estimates of variance at each dose level chosen; however, for practical reasons, a few nominal reductions in the program at some dose levels were made without appreciable reduction in reliability. A total of 218 dosimeters were required for each processor participating in the complete test program. Some processors did not offer service in all of the radiation categories, and, hence, chose to participate only in part of the test irradiation program.

The types of radiation used in the test irradiation program were chosen to simulate those encountered by people exposed to radiation in the course of their employment or education. Four radiation categories photon, beta, neutron and mixtures--were established to encompass these radiations.

The systematic bias and the "random" variation were chosen as performance features to be used in establishing film dosimeter performance criteria. These performance criteria are to some extent unique in that they require a separation of the bias and variance parameters in the performance analysis.

The action required on the part of a processor to correct for errors due to calibration procedures and methods which give rise to bias is different than the action required to control film processing and evaluation methods which give rise to errors due to variance. The bias aspect of these performance criteria is concerned almost exclusively with the accuracy of the calibration and the evaluation of film dosimeters. Action by processors to minimize or virtually eliminate bias should be relatively

straightforward. One needs to identify and correct the source of error in his calibration and evaluation methods. If the bias and variance parameters are not separated, it may be difficult to identify the source of performance difficulties and consequently to make the required changes.

The bias performance criteria were developed to encourage processors to eliminate any bias in excess of 10% (expressed as a percent of dose) or if this is not possible, it will be plausible for a processor to make an over-all bias correction. After excessive bias is eliminated or corrected for, a variance performance criterion needs to be met for a processor to be identified as meeting these film dosimeter performance criteria.

The variance performance criteria were designed to assure a high probability of passing the tests for each processor whose performance meets the variance specification. An important factor considered in the establishment of these performance criteria was the fluctuations that will occur in measured performance solely due to the statistical variations of the measurements. For example, to establish a variance performance criterion, expressed as relative error, at say 40% and to test rigidly against that value to determine compliance, actually requires performance considerably better than the 40% to assure compliance on every test. A processor meeting the 40% criterion with 95% confidence will fail 5% of the time on a statistical basis alone. If there are several test points all or nearly all of which the processor must meet, his ability to pass is rapidly decreased due solely to the design of the performance measurement system. The performance criteria advanced by this study have avoided this difficulty by designing performance criteria tests that take into account the statistical nature of the evaluation procedures. The χ^2 function used in the variance performance equations allows for the statistical variations that are normally to be expected in evaluation of the performance of processors. This test method provides maximum flexibility in designing the performance evaluation program and provides for the use of

various numbers of dosimeters at a various number of dose levels while still maintaining a constant required level of performance.

In summary, a set of variance performance criteria are presented, Tables 1, 2, and 3, and Figures 1, 2, and 3. The test procedure to compare actual performance against these performance criteria considers and makes appropriate allowances for:

- The confidence level, within which an adequate processor can meet these criteria on any given test
- The use of a various number of dosimeters at each dose level
- The use of a various number of dose levels within each radiation category
- The provision of an equally rigid performance evaluation for any combination of the above three factors.

TABLE 1. Variance Performance - 200 keV to 3 MEV Photons

<u>Dose Equivalent Level, mrem</u>	<u>Relative Error</u>
40	48
60	39
100	30
250	19
500	14
750	11
1,000	10

TABLE 2. Variance Performance - Uranium or ^{90}Sr Beta

<u>Dose Equivalent Level, mrem</u>	<u>Relative Error</u>
40	35
60	28
100	22
250	14
480	10
600	10
800	10
1,000	10

Table 3. Variance Performance - Fast Neutrons

<u>Dose Equivalent Level, mrem</u>	<u>Relative Error</u>
200	89
400	63
600	52
800	45
1,000	40

The performance of all processors participating in the test irradiation program was analyzed to determine how well current performance met the proposed criteria. Although the bias performance is not scored as "passed" or "failed" due to the use of a bias correction factor when bias is in excess of 10% (expressed as a percent of dose), it is of interest to examine how many processors would have been required to make a bias correction based on their performance in this experimental program.

In some subcategories, all processors were found to have biases greater than 10% and, hence, would have been required to make a bias correction. Averaged over all radiation categories, the percentage of dose evaluations within various bias ranges is given in Table 4. This table indicates that about 85% of all measurements reported had bias in excess of 10% and required some bias correction or bias elimination effort on the part of the processor to meet the proposed bias performance criteria.

TABLE 4. Experimental Results--Observed
Processor Bias Performance

<u>Type of Processor</u>	<u>Percent of Measurements Within Indicated Bias Ranges Averaged Over All Radiation Categories</u>			
	<u><10%</u>	<u><25%</u>	<u><100%</u>	<u>>100%</u>
Commercial	15	45	84	16
AEC Laboratory	24	56	97	3
Military	15	44	93	7

FIGURE 1
Variance Performance - 200 keV to 3 MeV Photons

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FIGURE 2
Variance Performance - Uranium or ^{90}Sr Beta

FIGURE 3
Variance Performance - Fast Neutrons

The performance observed in the test irradiation program is compared to the proposed variance performance criteria in Table 5. All test data used in constructing the variance performance tables were corrected for bias prior to variance analysis. Averaged over all radiation categories, about 75% of the tests were passed. Averaged over all radiation categories, about 60% of the tests were passed by the commercial processors, about 90% by the AEC contractor processors, and about 80% by the military processors.

TABLE 5. Variance Performance Compared to Proposed Performance Criteria
(Corrected for Bias)

<u>Radiation Category</u>	<u>Total No. of Processors</u>	
	<u>Pass</u>	<u>Fail</u>
1. Photon - 200 keV to 3 MEV	29	5
2. Uranium or ⁹⁰ Sr Beta	24	7
3. Fast Neutrons	20	7

A relatively few processors contributed a high percentage of the failures noted. A detailed analysis of the failures shows that three (27%) of the commercial processors gave rise to 50% of the failures listed for their group, three (20%) of the AEC Laboratory processors gave rise to 58% of the failures listed for their group, and three (33%) of the military processors gave rise to 60% of the failures for their group.

The experimental program conducted as a part of this study provided the data not only to derive the proposed performance criteria, but also to evaluate the current performance level of each processor relative to the developed performance criteria. The evaluation of the performance of individual film processors form the basis to determine whether a Film Dosimeter Evaluation Program is necessary and needed at the present time.

The study has divided performance into two variables, bias and variance. First, consider the bias that was found to exist among film dosimeter processors. Was the

bias observed of sufficient magnitude to require the specification of a bias performance criterion? Bias is a measure of the difference between the average dose evaluated when a number of film dosimeters are exposed to a given dose and the "true" value of the given dose. The bias factor is an important consideration in assessing and in controlling the performance of film dosimeter processors. If each processor had well-calibrated radiation sources and ideal calibration geometrics and dose evaluation methods, then no biases should exist.

This study demonstrated that significant biases do exist among film dosimeter processors. Biases ranged to several hundred percent. A bias factor of 100% means the dose evaluation may be in error by 100% and also any dose summation of many dosimeter evaluations may be in error by 100%.

Bias is an error that can be controlled or corrected for with relative ease. Biases that exceed a few tens of percent should be reduced or eliminated. Clearly, bias values exceeding 100% are not justifiable. Biases which result in dose evaluation errors of this magnitude bargain strongly for the need for improved performance with respect to bias and for an evaluation program to assure that bias factors are adequately controlled.

Bias could be virtually eliminated by the establishment of a central film dosimeter calibration facility. By providing calibration exposures to film dosimeters at a central calibration facility, each processor would be assured that his calibration film received the same radiation exposure as that received by every other processor. A top quality central calibration facility would be the key to bias elimination. The central calibration facility would provide a mechanism to avoid the very high bias values found for some processors and would essentially assure the elimination of bias as a significant factor in film dosimeter evaluations.

Second, consider the variance that was found to exist among film dosimeter processors. Was the variance observed of sufficient magnitude to require formulation or a variance specification? Variance is a measure of the variation in dose measurement

when a number of dosimeters are exposed at the same dose level. It is an important consideration in assessing how well a processor controls his processing and evaluation methods. In discussing variance, it is convenient to convert the variance to relative error values to more easily visualize its significance.

The relative error is the percentage error that may occur at the 95% confidence interval due to the variance, σ^2 , observed at dose level E.

This study demonstrated that significant variances, and consequently significant relative errors, do exist among film dosimeter processors. Relative errors to several hundred percent were observed. These are judged to be excessive. The observed performance of many processors with investments in facilities and equipment not exceeding that of typical processors demonstrated that adequate variance performance can be reasonably attained.

If film dosimeters are used as part of a radiation protection program, it would seem desirable to control bias and variance more precisely than seems to be currently achieved. A film dosimetry evaluation program would be necessary to determine that the derived performance criteria are met.

Two considerations suggest the need to have in operation a system to assure adequate performance in personnel dosimetry. First, there may be an intrinsic need to demonstrate that the performance of film dosimeter processors is adequate. Second, there may be sufficient indication that reasonable action would result in improvements.

Earlier in this report, the judgment was stated that some system is necessary if one wishes to provide some degree of assurance that film dosimeter processing companies and other groups providing this service are performing in conformance with some minimum performance criteria. It is difficult for those responsible for health and safety to fully discharge their responsibilities without reasonable assurance that personnel film dosimetry is being performed in a consistent, responsible and adequate manner.

The methods of implementation of a Film Dosimeter Evaluation Program are dependent on the degree of regulation which is desired or needed. Broad matters of policy have heavy influence, therefore, on alternate methods of implementation which achieve substantially different degrees of regulatory control.

In summary, the results of this study are as follows:

- Reasonable criteria to define acceptable levels of performance with respect to variance and bias can be established and administered.
- Excessive bias and variance exist among film dosimeter processors. These are found in all groups participating in the test irradiation study; commercial firms, AEC laboratories and military installations.
- A program that would provide an assessment of the quality of film processing services appears to be desirable. Three alternative lines of action could be considered, and under any one of these, a degree of achievement of this assessment would be obtained.
 - a. A Film Dosimeter Processors Evaluation Program administered on a required basis would afford a high degree of assurance of sustained adequate performance by commercial and AEC groups providing film dosimetry service.
 - b. A Film Dosimeter Processors Evaluation Program administered on a voluntary basis would provide most of the improvements of, but somewhat less overall assurance than, a full regulatory program.
 - c. A central Calibration Laboratory for film dosimeter processors would essentially eliminate the biases revealed by this study. This would yield important benefits even if no processor evaluation functions were included.